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Large Scale Data-Driven Delay Distribution Models of European Air Traffic Flow Network

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Abstract

This work aims to build different types of data-driven approaches in modeling European ATM Network Flow to capture the behavior of delay propagation over the network. To build proper network models and set their parameters, we have utilized historical flight track data, which includes last filed flight plans and actual movements. Through their comparisons, actual delay profiles of the airports and continental inflows/outflows were evaluated. In order to reduce the complexity of the models, most congested 103 European airports were held, and other airports were aggregated without considering their topological specs. Then, we have utilized these models to simulate the impact of local disturbances on the whole network through real air traffic data of certain days that disrupted due to capacity reductions issues such as heavy rain at an airport, an airline of controller strikes, runway construction, industrial events, etc. The results of these comparisons that performed by the certain simulations are reviewed to provide the performance assessment of the methods in demand-capacity balancing.

Keywords: Air Transportation; Air Traffic Modeling and Simulation.

1. Introduction

The air transportation industry and its role in modern life are rapidly growing. It is expected that the number of commercial flights will increase almost double from 26 million to 48.7 million and 13.5 trillion passenger-kilometer will be flown by 2030, which is almost the triple of what is flown by airlines today (see Airbus (2015)). The total number of new deliveries for both passenger and freighter aircraft are expected to be close to 32,600, while 14,000 passenger aircraft will be retired or converted to freighter (see Airbus (2015)). However, the airspaces have a fixed amount of capacity, and the number of airports to be built is not large enough to accommodate such increase in the demand. Therefore, the Air Traffic Management (ATM) system must go under an operational transformation to increase its efficiency to deal with this challenge. Meeting the capacity demand and minimizing arrival flight delays are among the most critical challenges of Flight Path 2050 (see ICAO (2011)).

New procedures and concepts that are being developed in SESAR and NextGen are leading to a global paradigm shift from air traffic ”control” to efficient air traffic ”management” fashion, which requires redesigning the ATM sys-

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tem. The first step to redesign such a complex system is to perform rigorous analysis through the existing information. Once we have the parametric model on the network, then one can add stochastic behavioral dynamics to catch the sporadic effects on the system. Airports of the air traffic network are most fragile components of the system as the most influential events to the traffic flow occur in there. Therefore, focusing on the airports on model construction is the most common in such studies.

In this work, we have constructed data analytic approaches for modeling the European ATM Network Flow to capture the dynamics of delay propagation over the network. To build a proper air traffic network for Europe, we have utilized historical flight track data, which includes last filed flight plans and actual movements, and estimated the parametric features of components of the network. Thorough the data analytics, actual delay profiles of the most congested 103 European airports were evaluated and other airports were aggregated to reduce the complexity of the large-scale European air traffic network. Specifically, three different data-driven network models were constructed: airport-based queuing network model (QNM); airport-based queuing network model with ground-holding (QNM-GH); and slot allocation model (SAM). Then we have compared their behaviors under stress caused by a mandatory capacity reduction (due to heavy rain, strikes, runway closure, industrial events, etc.) in aerodromes that we have seen in historical data. The results of these comparisons that performed through simulations for different problematic days are given to provide the performance of the methods in demand-capacity balancing. Following subsection provides previous research efforts on the model construction of air traffic network.

1.1. Previous Works

Several researchers focus on different approaches to model the air transportation network. Eulerian network models are generated to model en-route air traffic flow and strongly inspired by hydrodynamic theory, especially by Daganzo's Cell Transmission Model (Daganzo (1994), Daganzo (1995)) and the work of Lighthill, Whitham and Richards (Lighthill and Whitham (1955), Richards (1956)). The Large-Capacity Cell Transmission Model that uses a graph-theoretic representation of air traffic flow is represented in the study of Sun and Bayen (2008). A discrete time dynamical system is used to model the traffic flow on the network. In this model, traffic flow is modeled by a deterministic linear system with unit time delay. Another model is presented by Menon et al. (2004). The modeling technique is to aggregate the air traffic into control volumes, which are line elements. The model accounts ATC actions and handles merging and diverging air traffic flows. Bayen et al. (2006) use the partial differential equations derived from conservation of mass in a control volume and it relies on a modified version of the Lighthill-Whitham-Richards (LWR) partial differential equations (Lighthill and Whitham (1955), Richards (1956)). Controller design strategies are also applied to these models to regulate the aircraft count in different sectors under a legal threshold (see Work and Bayen (2008), Menon et al. (2006) and Sun et al. (2007)).

Machine learning is another approach to model the delay prediction in air transportation. In Rebollo and Balakrishnan (2012) and Rebollo and Balakrishnan (2014), a network-based delay prediction model is constructed. The model uses Random Forest (RF) algorithm and the aim of this approach is to predict the departure delay state of a certain route in the network instead of predicting individual flight delays. Tu et al. (2008) also focus on departure delay prediction using machine learning techniques borrowing ideas from Genetic Algorithm. Moreover, MITRE Corporation focused on network modeling to mimic local delay propagation and developed two different models to simulate of delay propagation on the nationwide airport and airspace network in the United States. The Detailed Policy Assessment Tool – DPAT (Wieland (1997)), which is the successor of the NASPAC, is able to propagate delays across the network when the capacity of an airport is reduced due to external events, but it does not utilize the information regarding aircraft itineraries, which might lead to unreliable predictions.

On the other hand, there are also agent-based simulation models for delay propagation, such as FACET tool (see Bilimoria et al. (2001)). LMINET and LMINET2 (see Long and Hasan (2009)) are national queuing network models that are model the airports as $M(t)/E_k(t)/1$ queues. The Approximate Network Delays (AND) model is another popular model that is designed by Pyrgiotis (2012); Pyrgiotis et al. (2013). The modeling approach in AND and LMINET2 are similar. However, calculating strategies of the local queuing delays are different. The advantages of this approach are that it is computationally cheap, and it can model both deterministic and stochastic effects. Another methodology, which is seen in Bertsimas et al. (2011) and Castelli et al. (2011), focuses on optimization based or algorithmic approaches. In Castelli et al. (2011), a slot allocation model is generated by considering the structure of the air traffic network as a mathematical programming problem, so interdependence of the slots at different